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Radar EMI at Sea

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Advanced Systems Branch
Space Systems Division

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

As quantity and complexity of electronic systems on Navy ships increases, so does the probability of RF interference between systems, even those located on separate ships. This report briefly describes the coupling mechanisms possible between systems including refraction, diffraction and forward scatter at microwave frequencies between 200 MHz and 4000 MHz and supplies data in the form of graphs and describes a method whereby the magnitude of the interference can be quickly calculated for the various sea environments.

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CONTENTS

RADAR EMI AT SEA

1.0 General

As the number and complexity of electronic systems on board modern Navy ships increases, the probability of direct interference of one system with another increases.

Such interaction is recognized when studying systems on a single ship but must also now be applied to intraship interactions with the use of high power, long pulse (or cw) radiating systems.

This document is intended to provide the analyst with necessary data whereby interference between a radiator and receiver located on separate platforms can be evaluated, at distances exceeding line of sight. Effects due to refraction, diffraction and forward scattering are included.

2.0 Technical Discussion

For detail analysis and derivation of the principles of refraction, diffraction and forward scattering, the reader is referred to Technical Note 101, "Transmission Loss Predictions for Tropospheric Communication Circuits", published by the U.S. Department of Commerce, National Bureau of Standards, specifically chapters 4, 8, and 9.

The data presented herein was generated by applying the concepts of this technical note to the specific environments under investigation.

2.1 Refraction

Refraction, that is the effect of bending of electromagnetic waves due to gradients in the refractive index of the atmosphere near the earth's surface have been traditionally accounted for by applying a correction factor to the radius of the earth. This means that, rather than assuming a curved path for the wave over a curved surface, the curvature of the surface is modified such that the wave path is a straight line.

Note: Manuscript submitted August 17, 1979.

For most calculations the relationship

$$a_e = \frac{4}{3} a = 8497\text{m} \qquad (1)$$

where a = mean earth diameter
a_e = effective earth diameter

is used to fully describe this phenomenon and is the assumption used to generate the data presented herein. A more precise description can be given by

$$a_e = a \left[1-0.04665 \exp\left(0.00577\, N_s\right)\right]^{-1} \qquad (2)$$

where N_s varies from 290 at the earth poles to 390 near the equator and is assumed to be approximately 308 for most areas of interest (although some data indicates that N_s = 350 would be more appropriate).

This phenomenon therefore has the effect of increasing distance to the horizon, permitting increased radar range before interference occurs.

2.2 Diffraction

The model used to derive diffraction properties is commonly referred to as "diffraction over a smooth earth".

In this model the diffraction attenuation (above normal path loss) is given by

$$A = G(x_o) - F(x_1) - F(x_2) - C_1(K,b^o) \text{ db} \qquad (3)$$

where $$G(x_o) = .05751\, x_o - 10 \log x_o \qquad (4)$$

$$x_o = dB_o \qquad (5)$$

$$x_1 = d_{Lt}B_o \qquad (6)$$

$$x_2 = d_{Lr}B_o \qquad (7)$$

and $$B_o = f^{1/3}\, C_o^2\, B(K,b^o) \qquad (8)$$

where $$C_o = (8497/a)^{1/3} \qquad (9)$$

and d is defined as total separation distance, d_{Lt} is the horizon distance from transmitter, d_{Lr} is the horizon distance from receiver, a_e is the effective earth's radius (see (2)).

K and b^o are dependent on wave polarization and dielectric constant, ϵ, and conductivity, σ, of the surface.

For this study, vertical polarization of the electromagnetic wave is assumed with $\epsilon = 81$ with $\sigma = 5$ for sea water being applied. For diffraction analysis, C_o is assumed to be unity and K, b^o, $B(K, b^o)$, $C_1(K, b^o)$, $F(x_1)$ and $F(x_2)$ are derived from the curves given in chapter 8 of the referenced technical note number 101.

For frequencies between 200 MHz and 4000 MHz, $B(K, b^o)$ lies between 1.56 and 1.59 with $C_1(K, b^o)$ approximately equal to 20.

The effect of diffraction on electromagnetic propagation can in general be described as an increase in total propagation loss over the predicted path loss for separation distances even slightly less than the horizon with continued coupling between transmitter and receiver beyond the horizon.

2.3 Forward Scattering

For long tropospheric paths the principal propagation mechanism is usually forward scatter. This phenomenon involves an interaction of the electromagnetic energy with the various atmospheric particles and ions causing a partial redirection of the impinging wave. This is not a bending or refraction but more closely resembles an absorption and retransmission from the interaction point.

Thus, this phenomenon depends upon the intersection volume of the radiation patterns of transmission and reception systems.

In the case of high gain or directional antennae, it is possible that there is no common or intersection volume associated with the main beams. The theory assumes isotropic antennae in that the intersection volume is always the maximum allowable and is accurate for the side lobe interaction case of directional antennae.

The forward scatter loss is given by

$$L_s = 30 \log f - 20 \log d + F(\theta d) - F_o + H_o \text{ db.} \quad (10)$$

where $F(\theta d)$ is the attenuation function
F_o is scattering efficiency
H_o is the frequency gain function
d is the sea level arc distance

For most applications only the first three terms of (10) need be considered.

To determine $F(\theta d)$, the value of θd must be defined as

$$\theta d = \frac{d_s \ d}{a_e} \tag{11}$$

Where d_s = arc distance between horizons or in terms used in section 2.2,

$$d_s = d - d_{Lt} - d_{Lr} \tag{12}$$

For values of $\theta d \leq 10$, which is the case of interest L_s can be approximated by

$$L_s = 135.8 + 30 \log f + 30 \log \theta + 10 \log d \tag{13}$$

where f is in MHz
and d is in Km
and the term $.34\theta d$ from technical not 101 (see ref. above) has been dropped.

The scattering loss derived from equation (13) exhibits increasing inaccuracy below a frequency of 400 MHz, the results being less than actual measured values.

2.4 Total Loss

Diffraction and scattering losses are two transmission mechanisms acting independently and simultaneously. Thus, the total energy received is the sum of the energy from each mechanism.

The diffraction loss A, defined by equation (3) is only the additional loss due to diffraction above normal path losses as would be experienced by line of sight transmissions. To determine the total diffraction mechanism loss including separation factors

$$L_{TD} = A + 20 \log \frac{\lambda}{4\pi d} \tag{14}$$

Thus, it is necessary to consider the parallel combination of the two loss mechanisms as defined by equations (13) and (14) to derive the total isolation factor.

3.0 EMI

A series of figures have been included in this report from which the interference between sea platforms can be determined.

The information necessary to define the problem is

h_t = height above sea level for transmitter
h_r = height above sea level for receiver
d = arc separation distance between transmitter and receiver
f = frequency of transmission
P_T = transmitter power (into antenna)
G_T = effective gain of transmitting antenna in direction of receiver
G_R = effective gain of receiving antenna in direction of transmitter
F_N = noise figure of receiver
B = instantaneous bandwidth of receiver.

3.1 Calculation of Receiver Sensitivity

Figure 1 is a plot of system noise temperature as a function of receiver noise figure for a typical radar system that includes a loss of .5 DB between antenna input and receiver. Included are two curves that relate antenna temperature of the receiving antenna to pointing angle above horizon.

After determining T_s for the receiver this value is used in Fig. 2 to determine system sensitivity, for various receiver bandwidths. Note that a minimum acceptable signal to noise ratio of 14 DB has been chosen. This value is considered the minimum acceptable limit for most radar systems but does not limit use of a system at lower values with reduced accuracy.

The resultant system sensitivity, S_s, will be used later to determine interference.

3.2 Diffraction Loss

Figure 3 defines free space path loss as a function of total arc separation between transmitter and receiver at various frequencies in the band of interest between 200 MHz and 4000 MHz. This frequency band has been chosen because of the extensive use of this frequency spectrum by Navy long range radars. This value P_L will be added to the diffraction loss A.

Referring to Fig. 4 the distances from receiver and transmitter to horizon are calculated, dependent upon height above sea level.

The value d_s, separation distance is found to be

$$d_s = d - d_{Lt} - d_{Lr}$$

and is used in conjunction with Fig. 5 to generate A, the diffraction attenuation.

Note that the loss A in Fig. 5 is not zero for $d_s = 0$; thus A may be real for negative d_s (not over horizon). Note also that A is never less than 0 DB even for negative d_s.

The loss A from Fig. 5 is added to the line of sight path loss P_L to yield the total diffraction-path loss L_{TD}.

This value, L_{TD} will be used later in determining interference.

3.3 Scattering Loss

For values of d_s (see 3.2) greater than zero the horizon to horizon angle Θ is derived

$$\Theta = \frac{d_s}{a_e} \text{ in radians}$$

where a_e is defined in (1) or (2).

Figure 6 is a plot of horizon to horizon scattering loss L_1 as a function of Θ.

To this value L_1 is added the loss term L_2 as derived from Fig. 7 which is dependent upon total arc separation distance, d, and frequency, f, giving the scattering loss L_s of equation (13).

L_1 is the term 30 log Θ of equation (13) and

L_2 is the sum 135.8 + 30 log f + 10 log d also of equation (13).

3.4 Interference

To determine the total signal strength into the receiver due to an offending transmitter

$$P_R(\text{DBW}) = \text{ATTN (DB)} + G_R(\text{DB}) + G_T(\text{DB}) + P_T \text{ (DBW)} \tag{15}$$

Two powers P_R will be calculated, one using the value for L_{TD} in section 3.2 and the second using L_s of section 3.3 for the term labeled ATTN in (15).

It should be noted that the antenna gains G_T and G_R are not peak antenna gains but those in the common antenna direction, or for over-the-horizon conditions, the direction

defined by a great circle path between antennae.

The total interference power P_{IR} is then defined by

$$P_{IR} = P_R(\text{diffraction}) + P_R(\text{scattering}) \qquad (16)$$

Note: Do not add DB but powers in eq. (16).

This value P_{IR} is compared against the system sensitivity S_s from section 3.1. A value of $P_{IR}(DBW) - S_s(DBW) = 12$ DB represents a reduction in radar range by .5 due to interference for the same S/N ratio.

4.0 EMI Studies

Based upon shipboard radars, examples of levels of interference that will degrade radar performance are included below.

In those instances where information about radar parameters and/or location was not available estimates have been made concerning necessary inputs.

Case 1. Interference created by 1 watt emitter transmitter at total transmitter/receiver separations of 10 KM, 50 KM, and 100 KM against AN/SPS-29 radar.

It is assumed that the SPS-29 is located 60 ft above sea level and the offending emitter is 45 ft above sea level. It is also assumed that each antenna, in the direction of interest has an effective gain of - 10 DBI.

The AN/SPS-29 radar has the following properties:

Frequency = 220 MHz
Elevation angle usually $< 30^\circ$ (assume horizon)
IF bandwidth = 200 KHz (based upon P.W.)
Noise figure = 4.0 DB

System temperature is estimated to be $675^\circ K$ from Fig. 1. System sensitivity (for 14 DB S/N) is determined to be -129.2 DBW from Fig. 2 assuming a bandwidth of 500 KHz. Based upon height above sea surface, the horizon distances are 13.2 KM for the offending emitter and 15.25 KM for the radar from Fig. 4. The total horizon separation is therefore 28.45 KM.

From Fig. 3 path losses are derived for the three emitter/receiver separations; 98 DB for 10 KM, 112 DB for 50 KM, 118 DB for 100 KM.

The diffraction attenuation is then obtained from Fig. 5 for the three horizon-to-horizon separation distances; 17 DB at -18.45 KM, 35.5 DB at 21.55 KM, and 59.0 DB at 71.55 KM. Note that for the first case the emitter/receiver separation is less than the horizon distance but diffraction attenuation is finite (extrapolate Fig. 5 for negative separations). The total diffraction attenuation:

115 DB at 10 KM
147.5 DB at 50 KM
177 DB at 100 KM

Based upon horizon-to-horizon separation the attenuation L_1 is derived from Fig. 6. In terms of horizon-to-horizon separation L_1 is undefined for -18.45 KM**, is -77.9 DB for 21.55 KM, and is -62.2 DB for 71.55 KM. Using Fig. 7 and extrapolating to the 10 KM case L_2 is found to be 215 DB for 10 KM emitter/receiver distance, 221.6 DB for 50 KM and 225 DB for 100 KM. The scattering loss is the sum of L_1 and L_2 and in terms of distance is

Undefined for 10 KM
143.7 DB for 50 KM
162.8 DB for 100 KM

Scattering loss is not defined for separation distances less than the horizon.

Clearly scattering is the predominant coupling mechanism at 50 and 100 KM whereas diffraction appears predominant at 10 KM. Note that at no time is the loss only that predicted by path loss at the frequency of the radar.

If the gain of each antenna is added to the chosen set of attenuations then interference is:

-135 DBW at 10 KM
-163.7 DBW at 50 KM
-182.8 DBW at 100 KM

Now system sensitivity was determined to be -129.2 DBW. From the above numbers it can be assumed that down to a 10 KM separation the AN/SPS-29 will not be degraded by a 1 watt signal. If however the offending emitter contains a 100 watt (+20 DBW) transmitter then the interference increases. At 10 Km, the offending signal is 14.2 DB above the sensitivity and the range is reduced to 44% of the initial value. At 50 KM however, the interference is negligible.

** L_1 is defined only for positive values of separation angle and is considered highly inaccurate for $\theta > 10^{-3}$ rad.

If the emitter power is increased to 1000 watts a further reduction in sensitivity will occur and may be intolerable at separation distances out to 50 KM or greater.

Figure 8 is a plot of interference power as a function of total separation distance for various transmitter powers. The radar receiver sensitivity has been added for reference.

Case 2. Interference with the AN/SPN-43 approach radar.

This radar is typically used at short ranges and could well have an elevation angle of 30 degrees (which will be used for calculations). Operating frequency is typically 3600 MHz with a bandwidth of 1.3 MHz and a receiver noise figure of 3 DB. System sensitivity for 14 DB S/N ratio is estimated at -128 DBW. For the same heights above sea level as for Case 1, the diffraction attenuation is

123 DB for 10 KM
181.5 DB for 50 KM
253.5 DB for 100 KM

For path lengths less than the horizon case the loss is now basically the free space line-of-sight loss as is evidenced by the 10 KM value above.

The scattering losses for the same separations are:

Undefined 10 KM
181.6 for 50 KM
200.3 for 100 KM

Once again diffraction (or line-of-sight) loss predominates at short distances whereas scattering is the major coupling mechanism at the greater separation distances. At 50 KM separation, the two mechaisms produce equivalent couplings and the total attenuation can be approximately 178.5 DB.

For antenna gains of -10 DBI and a transmitter power of 100 watts (20 DBW) the AN/SPN-43 radar range will be degraded by 25% with the emitter at 10 KM but now the EMI at 50 KM is negligible. At 50 KM a transmitter power of 10 KW would produce only negligible effects on the radar.

5.0 Conclusions

For separation distances within line-of-sight the path loss (see Fig. 3) is a good guide to interference phenomena. It is reasonable to assume that antenna gains in the appropriate directions are -10 DBI, representing average side lobe levels.

Beyond the horizon coupling rapidly becomes a scattering phenomena that for frequencies above 3000 MHz is negligible for separation distances beyond 50 KM.

Even though general areas of satisfactory EMI can be found, calculations based upon specific requirements in accordance with procedures outlined herein are desirable especially if the offending emitter is operating at power levels in excess of 1 KW.

Acknowledgements

The author would like to express his appreciation to M. Vosburgh, System Planing Corp., Roslyn, Va., for his assistance in developing a clear understanding of the phenomena involved in EMI at sea.

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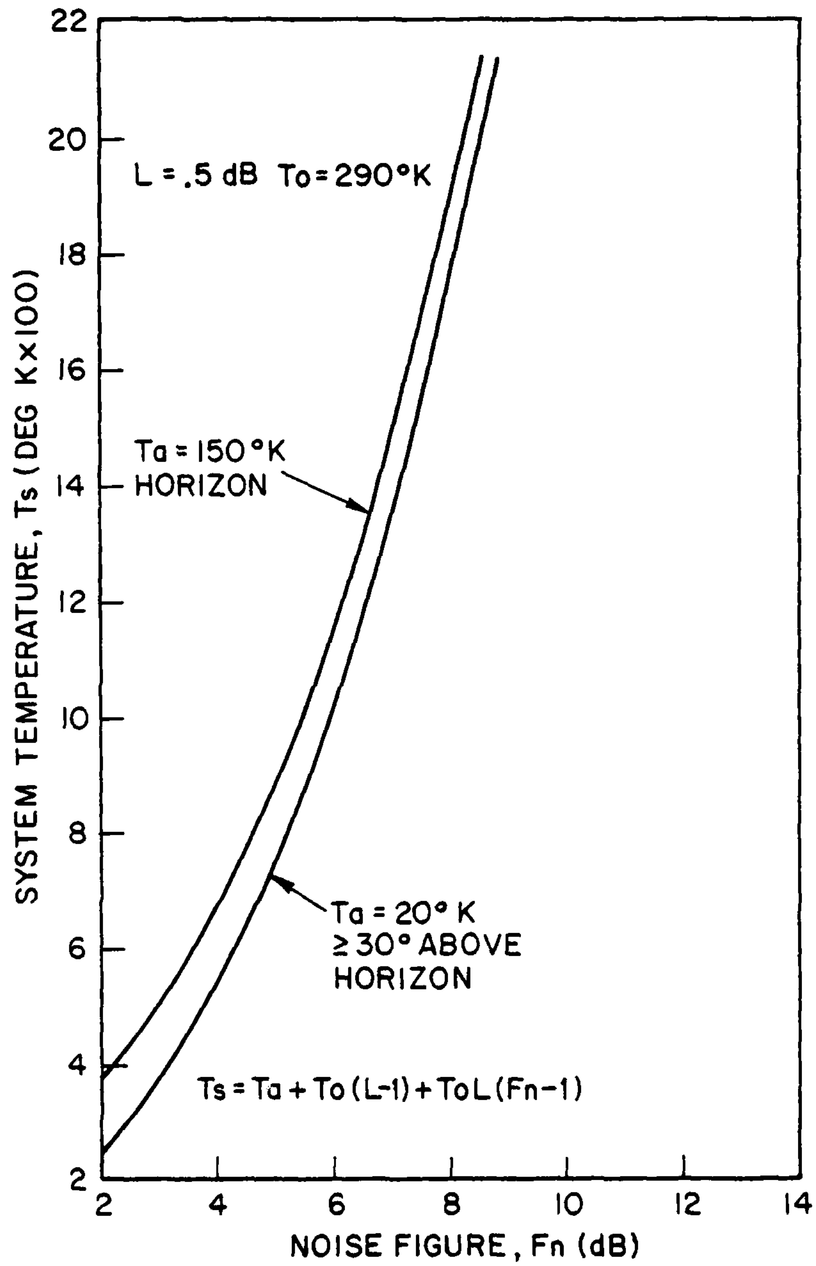

Fig. 1 — System temperature vs. noise figure

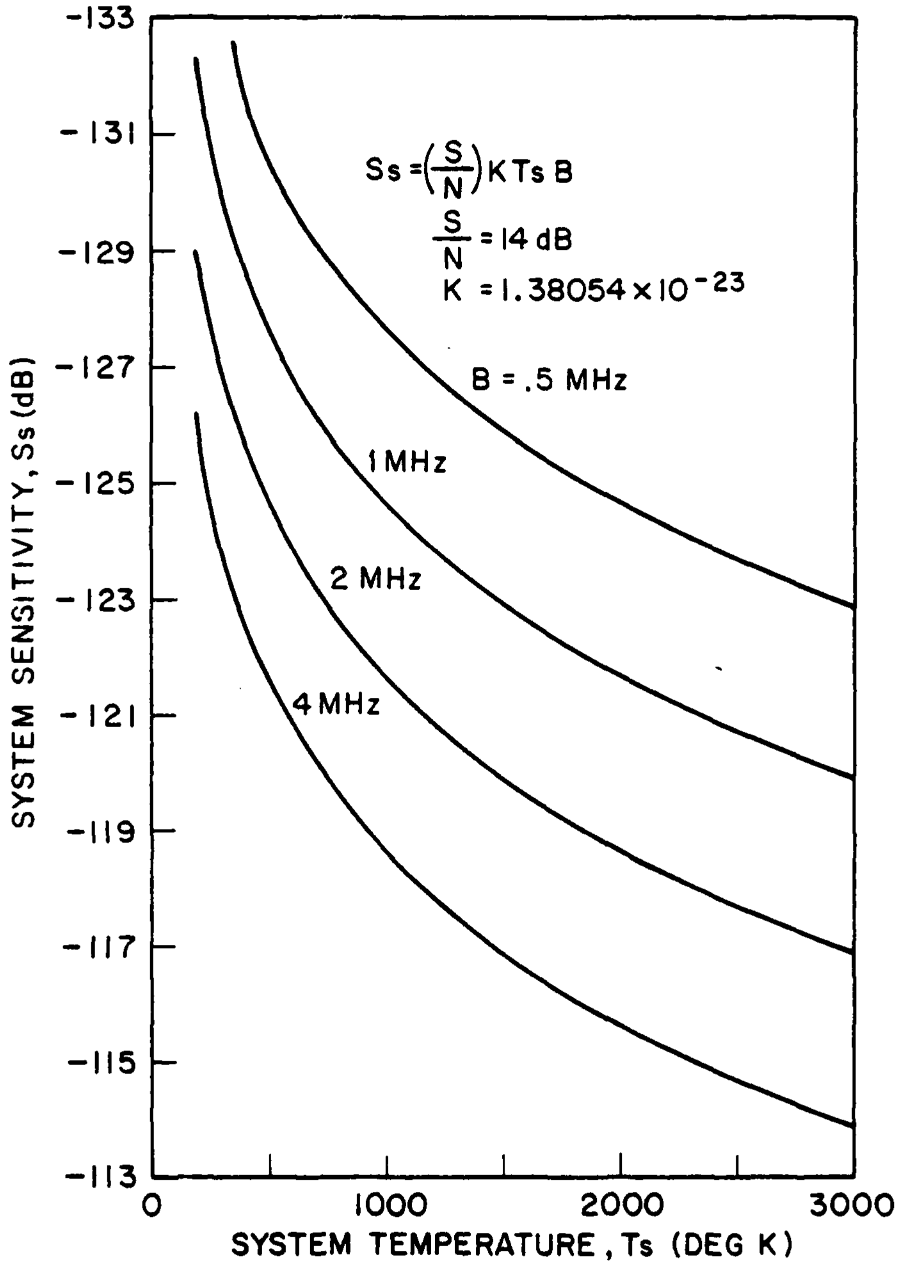

Fig. 2 — System sensitivity vs. system temperature

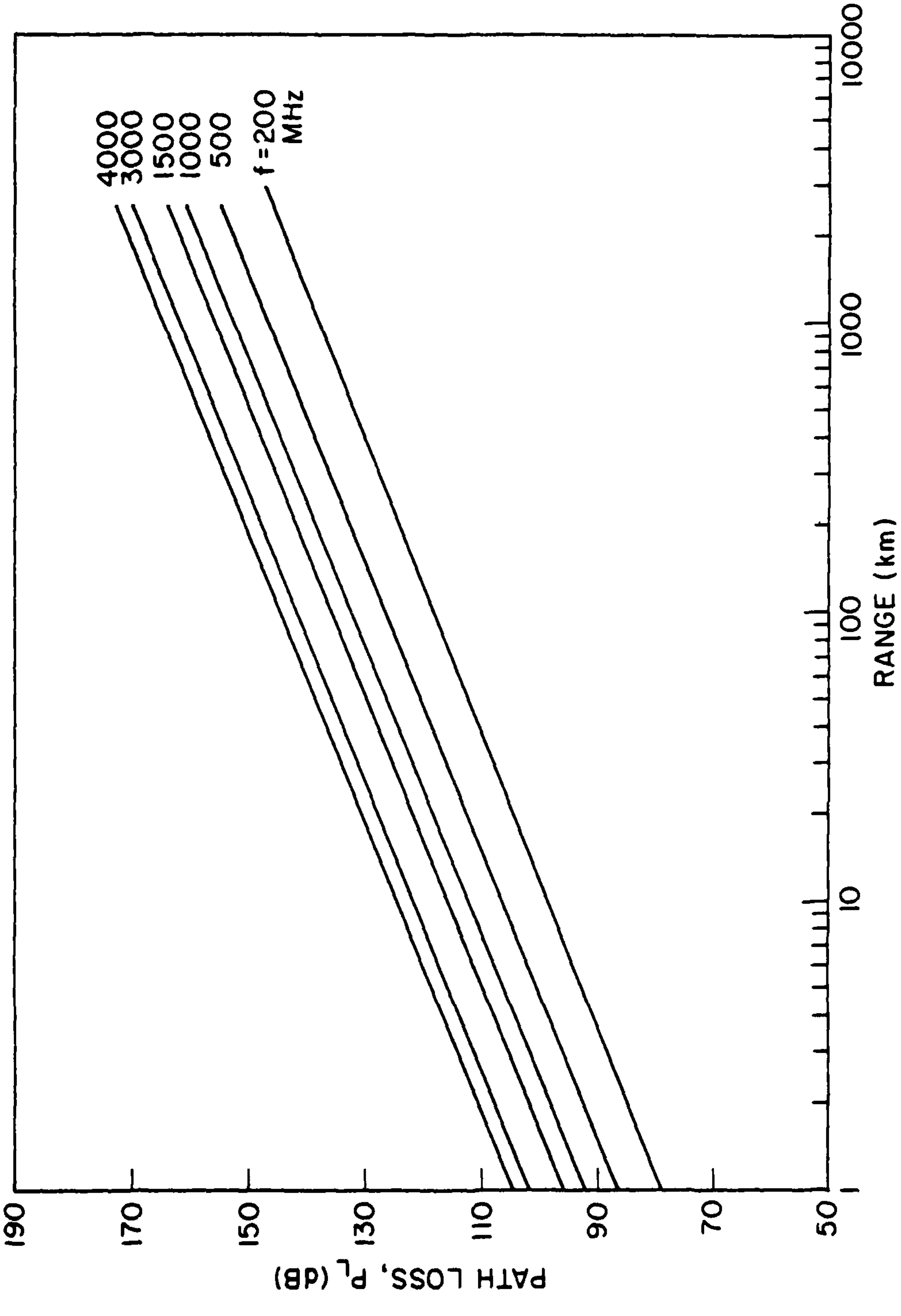

Fig. 3 — Path loss vs. range

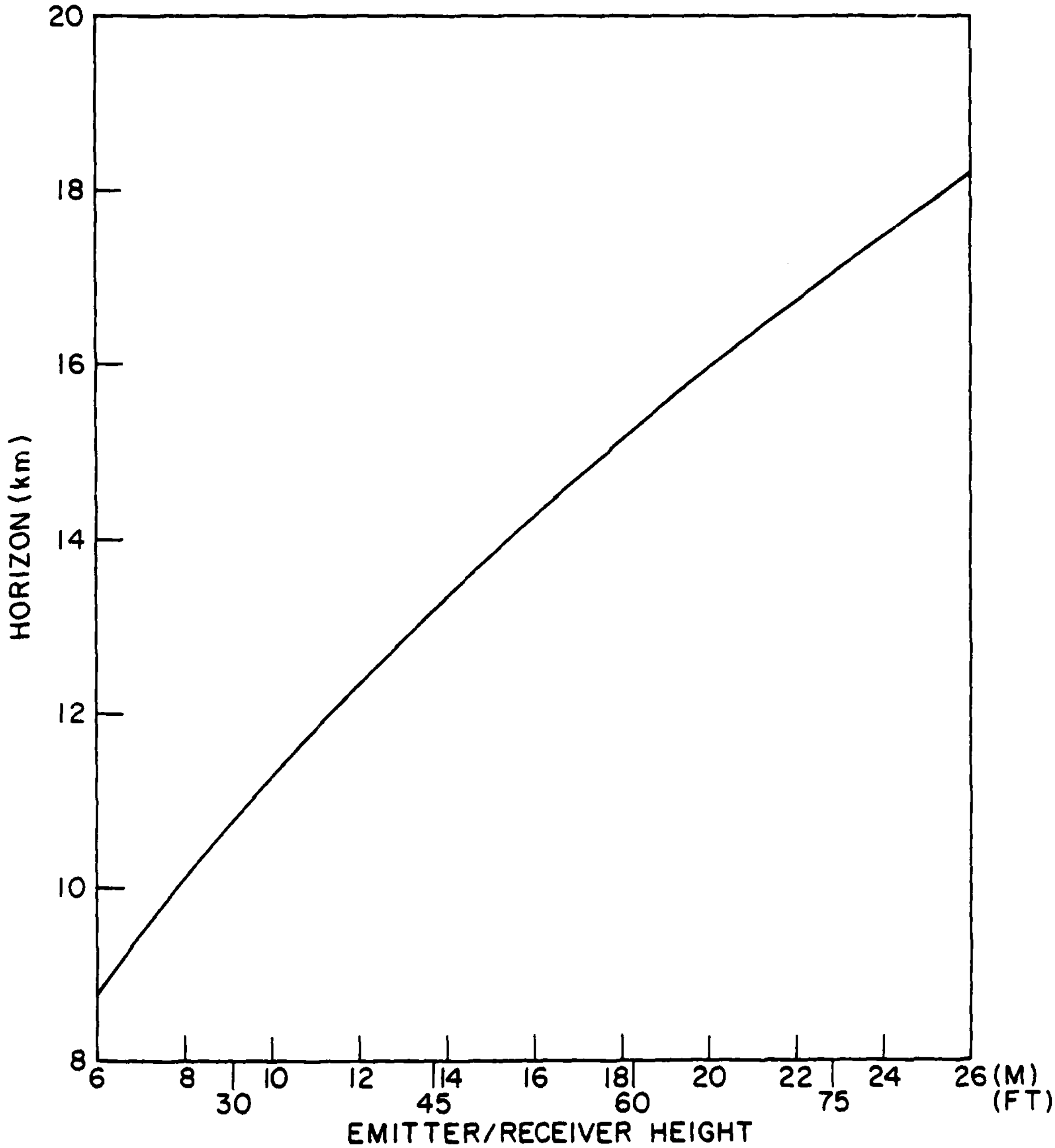

Fig. 4 — Horizon distance vs. emitter/receiver height

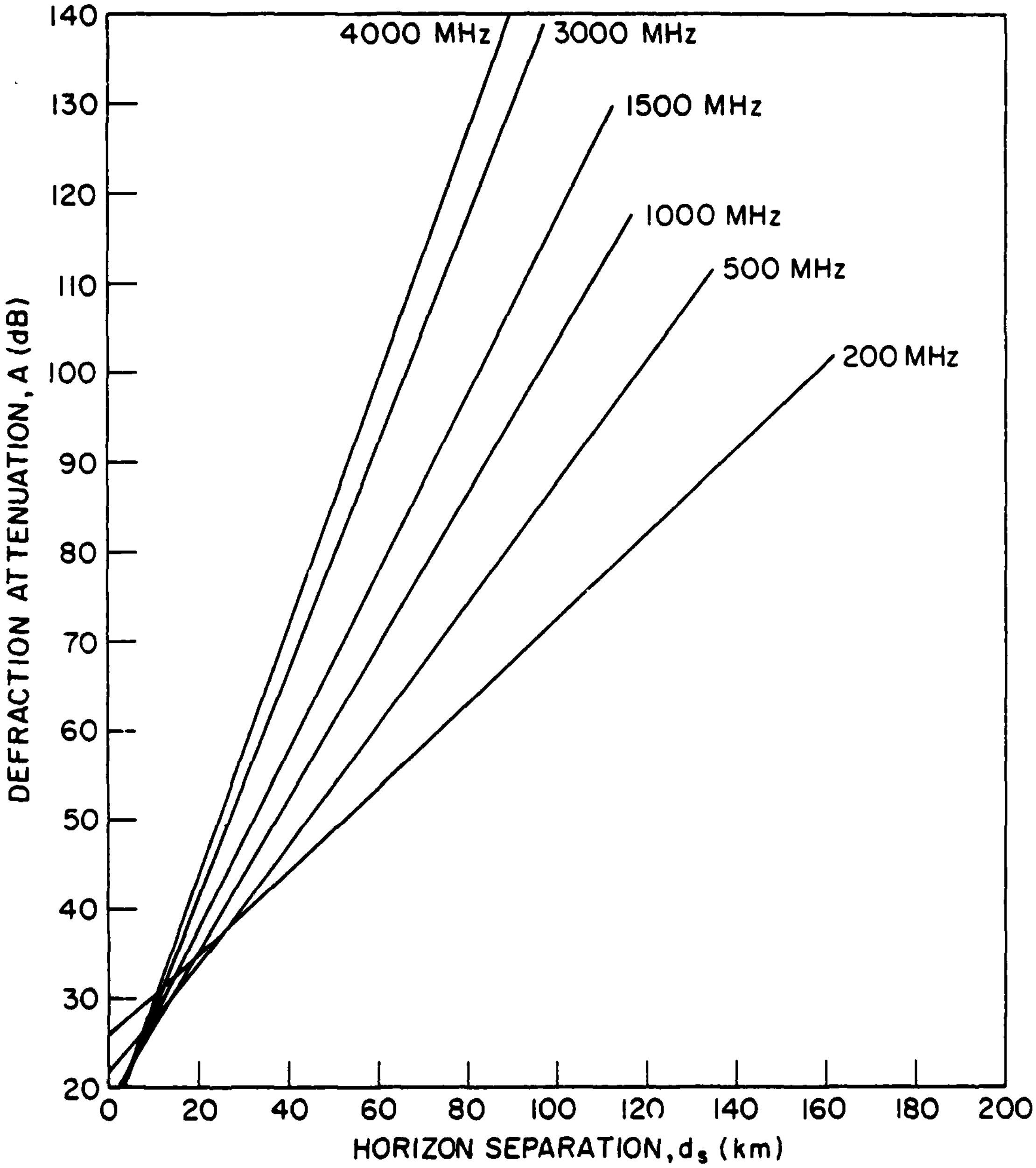

Fig. 5 — Diffraction attenuation vs. horizon separation

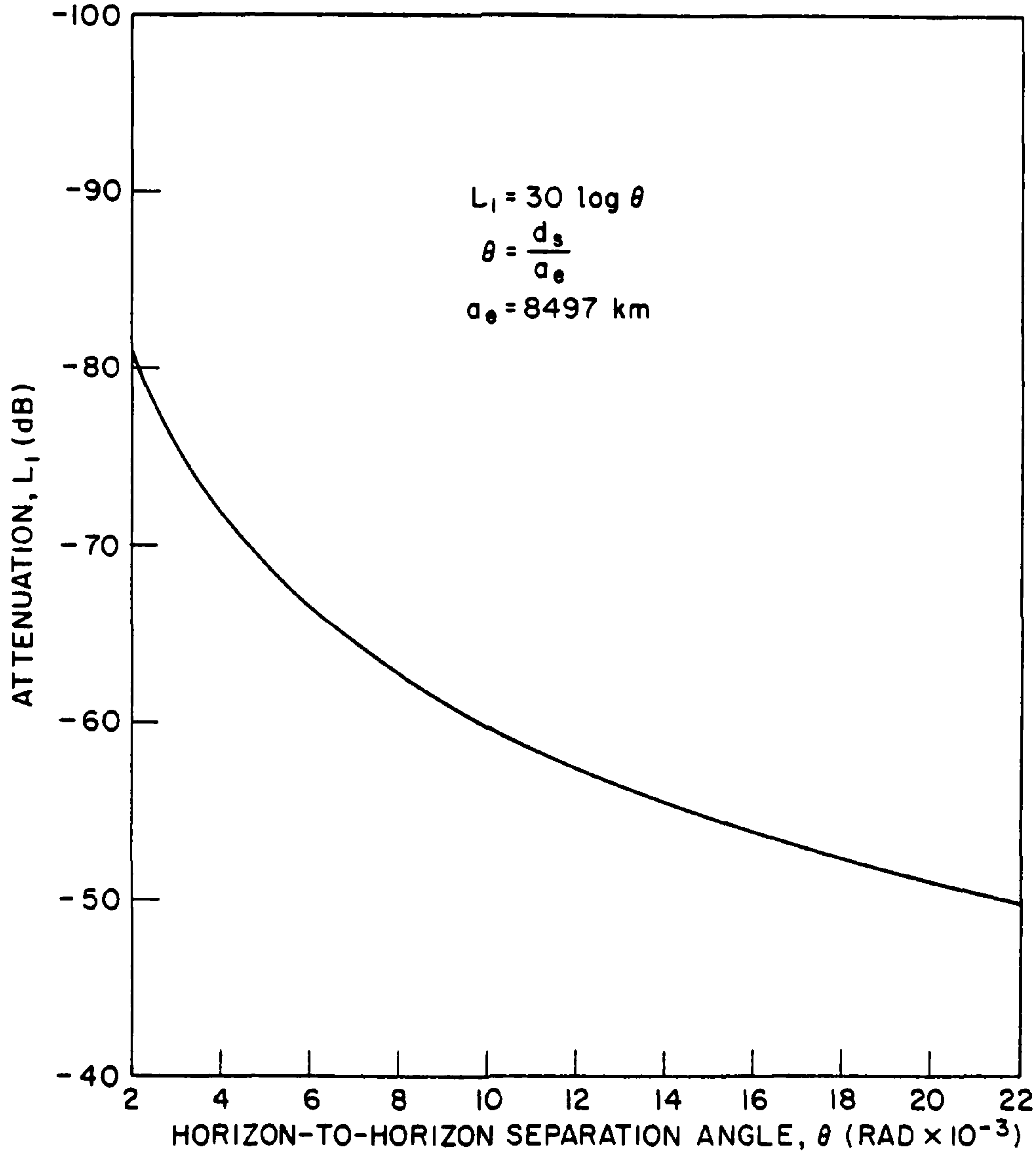

Fig. 6 — Attenuation L_1 vs. horizon-to-horizon separation angle

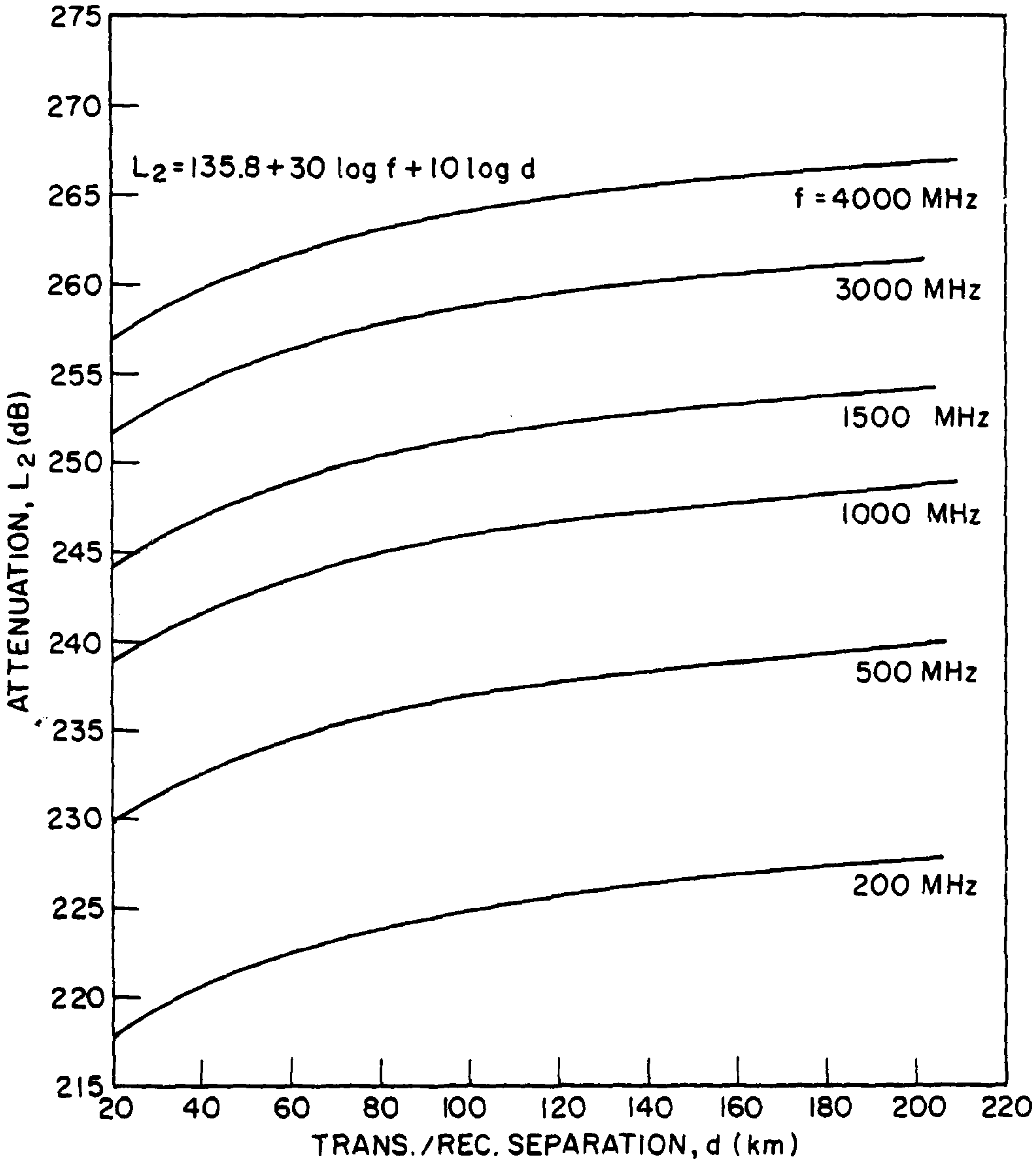

Fig. 7 — Attenuation L_2 vs. trans/receiver separation

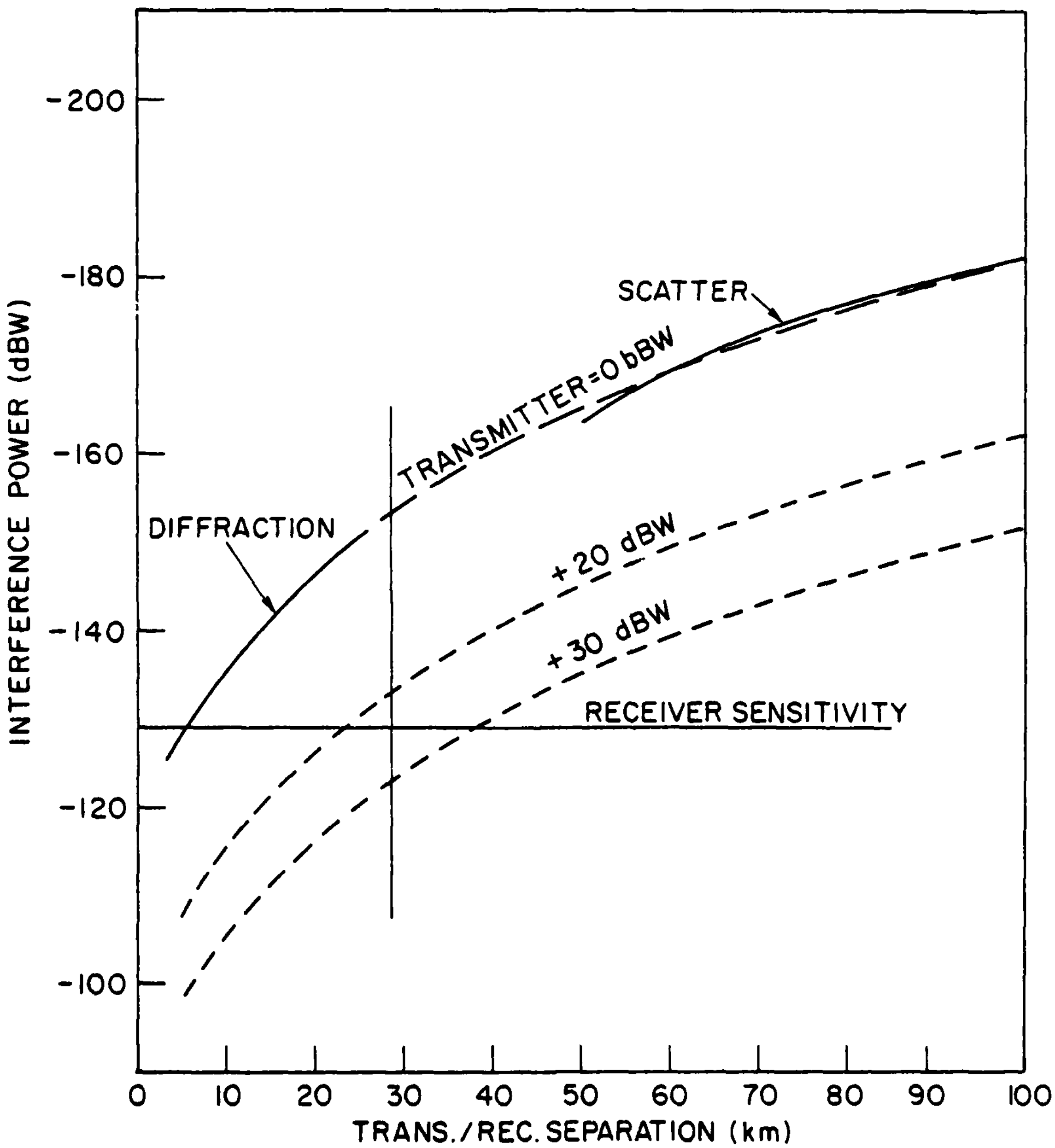

Fig. 8 — Interference power vs. separation distance for various transmitter powers, case 1